THE

PART PLAYED BY ELECTRICITY

IN THE

PHENOMENA OF ANIMAL LIFE

ADDRESS

delivered by Mons. Ernest Solvay, on December 14, 1893,

AT BRUSSELS,

WITH AN APPENDIX

CONTAINING

OFFICIAL DOCUMENTS

IN RELATION TO THE ESTABLISHMENT OF THE

SOLVAY INSTITUTE

OF THE CITY OF BRUSSELS

Translated, at the author's request, by J. W. MALLET, University of Virginia

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NEW YORK

PRINTED BY HERMANN BARTSCH, 87 FRANKFORT ST.

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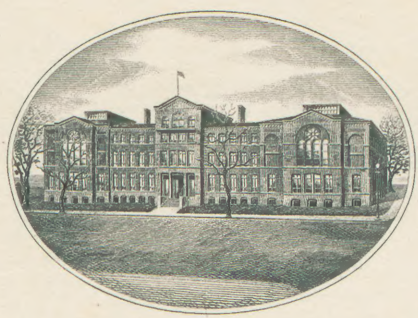

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THE

PART PLAYED BY ELECTRICITY

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GENERAL REMARKS

ON THE

Part Played by Electricity

IN THE

PHENOMENA OF ANIMAL LIFE,

IN CONTEMPLATION OF THE

EXPERIMENTAL WORK PROPOSED FOR THE SOLVAY INSTITUTE.

Address delivered by Mons. Ernest Solvay, at Brussels, on the 14th of December, 1893.

Translated, at the author's request, by J. W. MALLET, University of Virginia.

GENTLEMEN:—

I have thought that the time has come to bring you together and to place before you some brief statement of my views on the subject of biology.

I do not believe that I need explain to you at length the motives which have decided me to propose to the City of Brussels the creation of a University school of physiology; you are the friends of free University teaching; you understand as I do the practical needs of scientific instruction.

But, as you are already aware, the proposals which I have

made to the City and to the University* had a two-fold aim — the establishment of a special school of University instruction on the one hand, and on the other the foundation of a special Institute for experimental work devoted to electro-biological research.

I hold, indeed, that what before all else should be encouraged is original investigation, the discovery of new truth, especially in the domain of biological knowledge.

The physico-chemical sciences have triumphed on all sides. They hold sway over all the industries of modern life; the time is coming when they will take possession of life itself.

To hasten the coming of this time it is not enough that we build up schools of instruction. Biological *research* must be guided in the direction of Physics and Chemistry, and, in my opinion, we must set out with this profound conviction; that *the phenomena of life can and should be explained by the working of the physical forces alone which control the material universe, and that among these forces electricity plays a predominant part.*

It is with a view to contribute to the verification and development of this thesis, by observation and by study of the facts of experiment, that I have determined to found a special Institute for research.

I would now address myself to all those who, in the future, and even after I shall have ceased to live, shall undertake researches in the laboratories which are about to be opened; I would try to state the character of the answers which I

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* See the letter to the Administrative Inspector of the University, and the extract from the proceedings of the session of the Communal Council of the City — pages 59 and 63.

foresee are to be looked for from their labours to the great problem, as I understand it, of the nature of life. Having meditated much upon this problem, I believe that I have found some new points of view which it may be useful to make known to those who enter upon experimental researches in this direction. I aim at establishing a close correlation among the facts by tracing them back always to the foundation of physical principle. I introduce hypothesis when needful, as a lever, as a tool with which to open a new path for investigation.

The future will show to what extent my views are true, or how far I have been mistaken. However this may be, I hope that no one will misconstrue the motives which impel me to state here my ideas; when I think that I may throw some light upon obscure or disputed scientific questions I should reproach myself if I did not discuss them.

I dedicate this statement of my views to you who have been my first co-workers, to all those who are enamoured of these questions, and especially to my worthy friend, Professor Paul Heger.

I.

PRINCIPLES OF PHYSICO-CHEMISTRY.

§ I. Of the conservation and transformation of energy. — Specific character of electrical energy.

We know that in every case of chemical combination the quantity of heat disengaged, with positive or negative value, is equal to that which would be necessary and sufficient to decompose into its constituents the substance formed; these constituents are restored, by the occurrence of decomposition, to their original physical state.

This consequence of the principle of the conservation of energy is independent of the *form* of energy under consideration; hence it holds good in a case in which *electrical* energy is that concerned.

In one form or other, the external energy which brings about a decomposition restores to the constituents the *potential energy* which they have lost in the act of combination.

On the other hand we know also that electrical energy may be transformed directly and completely into heat, although the reciprocal statement is not true; and, finally, we know that the two forms of energy, electricity and heat, often make their appearance together in the same reaction, and that when this is so the ratio between the quantities of energy in these two forms varies with attendant circumstances, but *the sum of the quantities in question remains constant.*

Starting with these *data*, it seems permissible to assume that, in every case of chemical combination, electrical energy may exist before thermic energy, and that the latter may

be but the result of a transformation of the former; that, if this way of looking at the facts is but partially sustained by experiment, the reason is to be found in our working under conditions which cause the immediate transformation, in whole or in part, of electricity into heat.

In support of this mode of looking at the facts, let us notice that electricity is capable of decomposing a substance without sensibly raising its temperature, while this is far from being true in regard to heat; hence the product of an electrolysis is much greater than that of a dissociation due to heat alone. It follows that electricity appears to us as endowed with a peculiar and specific character, of which we shall have to take account.

This character manifestly does not of itself furnish a proof of the pre-appearance of electrical energy in an act of combination, but if we regard at the same time certain inferences, upon which I cannot here enlarge, but which will be noticed in a future memoir on the constitution of matter, we are led to attribute to my hypothesis almost the value of an established truth.

§ II. Of the relations existing between the phenomena of physics and of chemistry. Unity of the physical forces.

Firmly impressed by the idea that the great fundamental laws of nature *must* be simple, few in number, and universal, I have long sought, in a comparison of physical with chemical phenomena, so profoundly different as they are in appearance, the means of discovering a theory which shall permit us to connect them with a common origin.

Bringing together the chemical phenomena of combination and the physical phenomena of various kinds depending upon the force called *cohesion*, and relying upon the results of Sainte-Claire-Deville's work in regard to the parallelism which

exists between dissociation and vaporization, I have been able to assemble a collection of facts in nature which confirm my way of thinking, and furnish me the rudiments of a theory which I will only sketch here in outline.

We may, it seems to me, explain all phenomena, both physical and chemical, by assuming that every mass of matter (particle, molecule, or atom) is endowed with a specific character which is a mathematical function of its *temperature*, of its *pressure*, and of its *potential energy or its electrical state.**

Expanding this proposition, here stated in its most general form, we recognize that it affords us the means of explaining, not only the attractive force acting between the parts of matter of the same kind, but also and equally well the special *elective* power which characterizes the chemical force called *affinity;* that it enables us to interpret the variations which this latter force exhibits under the influence of changes in temperature, pressure, or previous electrical state (dissociation, action in the nascent state, &c.); that in short this very function of which we are speaking must be the expression of the physical force called *cohesion* or of the chemical force known as *affinity*, according as the substances brought together are *identical* or *different* in nature.

All phenomena, physical and chemical, are thus blended, and fall into two great classes:

1st—Endothermic phenomena, which consume, absorb, or render latent a certain quantity of external energy; and

2nd—Exothermic phenomena, which set free a part of the energy existing in the potential state in the ingredients which unite in the formation of a new body.

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* Since the potential energy may be expressed as electrical energy.

Let us go back now to what has been said, in § I., as to the pre-appearance of electrical energy in the act of chemical combination.

If it be true that chemical and physical phenomena present no essential points of difference, and are but the manifestations of a single and identical aggregate of causes, have we not ground for supposing, by reason of analogy, that in every *exothermic physical phenomenon* the energy set free appears, or tends to appear, first under the form of electricity?—that if we have not hitherto succeeded in completely revealing it in this form, it is because the very circumstances of our experiments have occasioned its transformation?

If this conjecture be vindicated, we shall be authorized to regard all the phenomena of nature, whatever they may be, as manifestations of electricity, without deciding beforehand anything as to the essential nature of this force.

This is the form under which the idea presents itself to my mind of the unity of the forces of nature.

II.

OF THE LIVING MOTOR.*

§ I. Of the nature of the living motor.

I said to you at the outset, Gentlemen, that the phenomena of life can and ought to be explained by the play of the known physical forces only. The views which I have just laid before you should serve us as the foundation for the study of biological phenomena. They will enable us, I hope, to give a real interpretation of the functions of living beings, and to understand some questions of general physiology which have hitherto remained very indefinite and very obscure.

Let us take as an example what concerns the nature of living motors.

Among the essential characteristics presented by the animal kingdom, one of the most striking is unquestionably the faculty of automatic locomotion, which has been called motivity.

The study of this distinctive quality leads us quite naturally to the most general consideration of the phenomena of life in their connected aggregate, so that we may conveniently take this as our starting point when we propose to unfold the part taken by the forces of inanimate nature in connection with the phenomena in question.

* I have briefly set forth the ideas of this chapter in a letter, of the 25th of July, 1887, addressed to Professor Heger. See: "The Programme of the Solvay Institute, by Dr. Paul Heger, Brussels, 1891.

Since motivity is essentially inherent in the nature of the living animal organism, we may say that an animal is a motor; further than this, we have good reason to believe that an animal is an electric motor, as I will now try to show.

Proceeding by the method of exclusion, we see at the outset that motivity cannot arise from a dynamic transformation of potential energy of the kind presented to us in a hydraulic motor, for we perceive neither a reservoir of liquid nor a fall capable of being turned to account.

Neither can the cause we seek be found in a purely thermic transformation of the same kind as that exhibited by gas engines, hot air engines, and steam engines, to which contrivances no one would think of comparing a muscle.

On the other hand, electricity lends itself to a satisfactory solution of the problem before us, a solution to which it will be well that we give our attention, at any rate until the future shall have revealed to us the existence of some other as yet unthought-of mode of transformation of energy, if so be that such a mode exist.

Laying aside then, finally, on the evidence before us the supposition of hydraulic action, let us examine more closely the two other hypotheses, and let us especially compare the yield in mechanical energy of a thermic or electric motor with that of a living motor.

We know that the most highly improved thermic motors do not give more than about 8½ per cent. of useful effect; the theoretic limit to the yield of steam engines is 17 per cent., and to that of gas engines 21 per cent. On the other hand, let us look back to the experiments of Hirn and Helmholtz; we find that we must assign to the yield of a muscle a mean value of more than 30 per cent.

It is impossible, as we see, to compare to this useful effect the far inferior yield of the thermic motors of human contrivance; the difference is so great that, without reference to certain physical impossibilities pointed out by Hirn, it suffices to make us give up the hypothesis of a thermic cause, in the sense in which we have just spoken of it.* The idea of electrical transformation presents itself in quite a different light, since in this case, the yield in mechanical

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* Recent researches, which we owe to Professor Engelmann, seem to prove that calorific action is not unconnected with the working of muscle.

In the main, every one agrees in assuming that it is the energy set free by the play of the chemical affinities acting in the muscle which is there converted into mechanical work. But what is this energy; is it heat or is it electricity? since we know that chemical reactions produce both the one and the other. I assume that it is electricity, because, as we have seen, its power of transformation is greater than that of heat, since it can always produce the latter, but cannot always be produced by it.

Let us compare several processes leading to the same result, in order to define with sharpness our mode of viewing them, and let us select an example applying to thermic motors themselves.

We have some water already raised to the boiling point; we place it in the cylinder of a steam engine, so that mechanical work can be obtained as the direct result of its vaporisation as soon as this change of state shall take place.

Three means present themselves to bring about the vaporisation of the water: a chemical process, an electrical process, and a thermic process. Thus, it will only be necessary in the first case to add to the water concentrated sulphuric acid, already brought to the temperature of boiling water; in the second case to pass through the water an electric current of sufficient intensity, but with electromotive force less than that which would decompose the water; and in the third case to introduce into it any body of sufficient mass, already raised to a temperature sufficiently above that of the water.

We see at once that in the first and second cases we obtain the mole-

effect is much greater and is comparable to that of the living motor.

Proof of this is furnished by all our electrical apparatus, transformers, motors, or contrivances for the production of energy. In most forms of voltaic battery, for example, if we consider the total quantity of energy set free, we find that of this 50 to 80 per cent. makes its appearance in the form of electricity and the remainder in the form of heat.

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cular work of change of physical state, and the consequent mechanical work, without having to recognize a temperature higher than the boiling point of the liquid, so that we may say, and even ought in strictness to say, that in the first case it is the energy arising directly from the exertion of chemical affinity, and in the second case it is electricity, that is transformed into the two forms of action—molecular work, and mechanical work.

Let us say then, to still speak logically, that it is electricity with which we are concerned in both these cases, since if it were heat in the first case the thermometer would indicate, as in the third case, the existence of a temperature above that of ebullition, with subsequent fall of temperature and degradation of thermic energy, which is not the fact.

We have taken as our example one of the cases most favorable to the thermic cause, since the cycle of Carnot is applicable to it, and use is habitually made of it in motors for industrial purposes. Nevertheless in the comparison as we have made it, the advantage is on the side of electricity; with still more reason must this be so in all other cases and especially in that of animal muscle.

We might even reasonably assume that the thermic energy which undergoes degradation by a fall of temperature, thus serving to bring about a change of physical state, as in the third case of our supposed example, transforms itself spontaneously into electrical energy, so as to produce the observed effect in nearly the same way as that of the second case; we should in this see how little difference there may be in reality between processes, differing in appearance, but having a unity of essential nature which comes near to being completely revealed to us.

The comparison which we have made, and its discussion, justify, I think, the conclusion that a living animal is an electric motor, and in fact it may be said that we observe in the very midst of the living apparatus the transformation effected of the initial (potential) into mechanical or thermic energy.

§ II. Of the seat in the animal body of electrical manifestations. Electrogenic apparatus.

If we refer to this source the energy displayed by the living animal, we have to examine where and how reactions occur which produce electricity.

Oxidation of organic matter takes place in all the living cells; it takes place even in the blood and in the lymph at the expense of the chemical constituents carried forward by these fluids and not as yet endowed with organized structure. All the tissues take part in this process of internal combustion; all must thus contribute to the supply of energy necessary to the living being.

But the relative importance of each of the tissues varies greatly in this respect; to convince ourselves of this we need but, for instance, contrast the physiology of muscular tissue with that of connective tissue.

The preponderant importance of the part played by muscular tissue is manifest; we know, in fact, that, when work is being done, the muscles come in for 70 to 80 per cent. of the total oxidation taking place in the animal economy.

The glands, which represent apparatus composed of cells of great vital activity, also undergo rapid oxidation.

Internal oxidation is for us the source of electricity. This process goes on chiefly in the muscles and in the glands; hence we give to these portions of the whole organic structure the name of *electrogenic* apparatus.

It is interesting to notice that the tissues which are the seat of most active oxidation, as the muscles and the glands, are richly provided with nerves, while those in which oxidation is feeble, as the cartilages and connective tissue, are but poorly supplied by the nervous system.

May we not use this fact—a very important one in my opinion—to establish an analogy between each animal organism, simple or complex, *amœba* or man, and the cell or single element of a voltaic battery? Thus the readily oxidizable tissues, forming the electrogenic apparatus, would play the part of the negative plate, the fluids producing oxidation and hydration that of the positive plate; the nerves would serve to close the circuit.

We should thus recognize in the economy of the living animal the chemical duality necessary for the production of electrical energy; should we not, consequently, be justified in considering this organism as a true physiological battery? If so, we ought to follow up the comparison, and try to understand how this battery works, what is the nature and what the extent of its circuit, what are the causes which make its discharge to vary, and finally what becomes of the energy which it develops.

§ III. Of the physiological voltaic battery.

In every battery the existence of available electrical energy is manifested only in so far as the electricity is able to flow off by appropriate conductors to parts of the apparatus where it may be utilized or transformed.

In default of such an arrangement—in the case, for instance, of a battery short-circuited by means of a conductor of low resistance, we perceive nothing but a development of heat

which seems to be the immediate result of the transformation of energy which occurs, but which, in accordance with what we have said as to the pre-appearance of electricity, may here again be regarded as a secondary phenomenon.

To justify the use of the expression physiological battery or pile we have at the outset to prove that there exist in the animal organism lines of least electrical resistance (or behaving as such) capable of giving direction to the electricity disengaged, of conducting and distributing it.

But I have good reason for believing that this part devolves upon the nerves, and that wherever they are developed and ramified they gather up a part of the electricity produced by the electrogenic apparatus and convey it to points where it reappears unaltered or transformed.

The slight oxidizability of nervous tissue and its great functional importance lend, moreover, support to this mode of looking at it.

In what way does the propagation of electricity in the nerves take place?

This question is certainly destined to occupy a large place in the programme for the experimental work of the Institute.

To answer it there will be need, it seems to me, for seeking first of all to complete our knowledge of the constitution itself of the nerve fibre, afterwards to study very closely the electro-physical properties of nerve tissue,* to investigate under

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* A first result of investigation in this line has already been obtained: see Solvay, Heger and Gerard—*Preliminary communication on the subject of the differences of potential existing in nerves in a state of activity.* (Bulletin de l'Académie royale de Belgique, 3e. série, tome XXI., no. 6. 1891).

what influences its electrical resistance varies, to determine finally the nature of the process itself by which the nerve current is propagated toward the organs where it is utilized. The inmost nature of this process is as yet unknown to us, and I do not understand that it is to be regarded as identical with the propagation of electricity in a metallic conductor. I limit myself then, for the present, to a single remark on this point—already proved to be true—namely, that manifestations of nerve action are always accompanied by variations of electrical condition.

I will not enlarge further upon these questions, important as they are, so as not to go beyond the plan of a merely general statement of views.

No one among you, moreover, can have overlooked the great interest of the researches of which these points will form the subject in the new Institute.

§ IV. Of the part played by the nerves in the phenomena of stimulation.

Muscle and nerve respond to stimulation of mechanical, thermic, chemical or electrical origin, but the last of these is attended with especially remarkable results.

Electrical influence is in fact by far the most powerful and extended in its effect, whether it be applied directly to the muscular tissue, or above all if it be applied to a nerve.

On the one hand, if a muscle be directly stimulated by a shock, a drop of acid, or a prick with a sharp point, we produce but a limited local effect, while on the contrary, if we act through the medium of a nerve we call forth generalized effects, whatever be the stimulus made use of, and it is the whole muscle that contracts as if each of its parts were electrified.

To obtain the same result without having recourse to a nerve as medium, it would be necessary to apply the stimulus simultaneously to all the elementary fibres of the muscle.

These facts have a double bearing: they seem to justify the idea of attributing to the nerves the part of conductors, and show also that electricity is the form of energy which lends itself better than any other to propagation to a distance, and to distribution in the living organism.

§ V. Of muscular contractility.

Although stimulation gives rise to electrical manifestations, it does not follow that the appearance or presence of electricity is necessarily dependent upon the occurrence of external stimulation.

I am much rather inclined to believe that the *physiological electric battery is always in a state of activity*, and that a muscle works—that is to say, gives out energy produced by this battery—even when it accomplishes no external work.

A muscle is an elastic body, more or less stretched, capable of being progressively contracted by the electric current, up to the point of producing an external mechanical effect. As the current diminishes the muscle relaxes, as the current increases it contracts, and we may say that its *tonus* or intensity of contraction is some function of the quantity of electrical energy employed.

On the other hand it seems evident that it is in consequence, not of a static, but of a dynamic action that the muscle as an organ maintains its state of contraction.

It behaves like a spring upon which a jet of water constantly plays, and not like a spring loaded with a weight.

In the former of these two cases, the dynamic stress, constantly kept up, is exerted against work, which involves expenditure of the moving fluid, and consequently a certain amount of energy. In the same way the sustained contraction of a muscle also demands a continued supply of energy.

The physiological battery operates then to furnish this energy, even when the muscle is at rest, and as no external work is accomplished in this condition all the energy furnished is transformed into heat.

It would be easy to multiply illustrations of this condition of special equilibrium; we find it notably exhibited in the case of a ball supported on a jet of water, and in that of a soaring bird which contends with the action of gravity by the rhythmic strokes of its wings.

§ VI. Of the variability in yield of energy by the animal organism.

It is easy to see that the quantity of energy consumed must increase when the state of rest is followed by that of activity from whatever cause, during which external and internal work are superadded to that of the *tonus* existing during muscular repose. The reaction of the organism is not constant; it varies in intensity with the condition of sleep, of wakefulness, and of work.

The investigations of Hirn and Helmholtz even give us the means of establishing the law of this variation for one and the same person. Thus, if we represent by unity the quantity of available heat produced during sleep, the corresponding number for the waking state will be 4, and for the state of normal muscular activity 7.

It must be then, of absolute necessity, that the yield or output of energy of the physiological battery can regulate

itself in due proportion, so that there shall never be either excess or deficiency.

Where shall we find the seat of this regulating action if it be not in the nervous system itself, with the importance of which as an apparatus of stimulation we have already taken note?

Assuming that the nervous system is not the producer of energy, but that its function is only to distribute it, must we not hence conclude that it is by means of its stimulating power it can modify, hasten or retard this distribution?

§ VII. Of the general reason for the existence of the nervous system.

We may picture to ourselves simply enough, in general principle, the reason for the existence of the nervous system, if we represent a nerve as the main path by which electrical energy is carried from the point at which it originates to a nerve centre, and from thence to an organ of expenditure.

In proportion as we ascend in the scale of matured animal forms, or in that of embryonic stages of development, and as we study more and more perfect organisms, we observe the muscular and nervous systems develop in extent and at the same time increase in the complexity of their structure and functions. In proportion as the embryo undergoes development, the nerve fibre elongates and becomes the seat of increased electrical resistance.

Thus the nervous net work ceases to be able to carry more than a continually diminishing part of the total energy. The greater part, forced to undergo utilization at the seat of its production, gives to the muscular fibre its peculiar character, and brings about its contractility or tonicity, as we have seen in § V.

It would be interesting thus to make a comparative study of nerve and muscle, as well from the physiological point of view as from that of anatomical structure, in the embryo, in the young and in the adult animal. Setting against each other the results thus obtained I think that we should have the explanation of the great difference in the mechanical value of the muscular system at different stages of individual development.

I doubt not that in such an investigation we should find one of the essential grounds of experimental fact for the thesis which I have undertaken to maintain. I therefore invite your full attention to this question. As for the great trunks of the nervous system, as well of the ganglionic as of the cerebro-spinal portions, they would be found to serve after all only for the conveyance of energy in the quantity needed to produce the required effects of stimulation, and under the conditions which we have stated all would go on *as if* the whole amount of energy produced in the electrogenic apparatus really circulated through the entire network of the nervous system.

The verification of this idea forms one of the essential parts of the task in store for the new Institute.

I will add here, by way of remark, that it is possible to find a reason for the necessary complexity which is displayed in the network of nerves in the animal body.

If we reflect upon the stage of progressive evolution of an inferior animal, or upon one of the earlier phases of development of an embryo, we understand that in proportion as nerve-trunks take their rise in the neighbourhood of each other, differences of electric potential, existing between certain points of these trunks, tend to give rise to new trunks, super-

added to the former, and the presence of which helps to render electrically dependent upon each other the different parts of the electrogenic system.

Let these anastomoses be multiplied *ad infinitum*, without losing sight of the fundamental idea of the system, and we shall be able, as it seems, to succeed in explaining the governmental order which reigns throughout the whole nervous system, from the smallest sporadic ganglia to the brain, which is itself the centre of centres.

§ VIII. Of the part played by sensory excitations.

Let us now investigate how the nervous system may play the part of stimulator while drawing its functional energy from the reaction of the whole organism and how it comes to regulate the operation in all its variations of the physiological battery.

Nothing seems to stand in the way of our looking on the series of multiplied nerve-trunks which constitute the nervous system of one of the higher animals as closely analogous to an ordinary system of wires for the distribution of electrical energy, in which whole series of apparatus for the consumption of this energy (lamps, electric motors, &c.) are branched off from a great source of production of electricity at a central station.

We may assume all of these pieces of apparatus for the utilization of the current to be regulated by instruments electrically connected with the central source of power, which instruments themselves consume in their operation a certain share of the available energy, and represent so many secondary derivations of energy from the system. Finally, to complete this ideal scheme, we may imagine each of the pieces

of apparatus for the utilization of the current to be furnished with an "annunciator"—an instrument operated electrically—which shall give notice to the regulating apparatus of anything going wrong at the point at which such instrument is placed.

The aggregate of all the regulating apparatus in such a system forms, to my eyes, an image of the brain, and the instruments which give notice of what may occur at the various outlying points in the system are but the analogues of the organs of sense.

Moreover, nothing prevents the parts of such a system being arranged so as to produce apparent automatism; such would be the impression conveyed by the innate character of the reflex actions arising from the structure conferred upon the system.

As for the sense impressions, the predominant part assigned them in such a distribution of energy will be to act upon the regulating apparatus, and by their means to modify the conditions of output of energy.

As the effect of influences from without acting upon the organism will be to oppose or to favour organic activity, in those parts where such influences have long tended to favour such activity the organs of special sense will have been formed and developed, and will have become the normal stimulators of vital action.

In such a system, provided the normal organism be not called upon for more than a part of the energy which it can produce, the actual production must essentially correspond with the demand for it; the physiological battery has, in the sensory organs, a true regulating apparatus capable of adjusting the amount of vital oxidation to the direct or indirect

excitations which come from the environment: the whole matter appears as if the stimulations of sense impressions set up conditions more favorable for the genesis of energy by increasing nerve conductivity, perhaps by a swelling up and consequent increase of contact or compression of the material of the axis-cylinders. The flow of energy thus produced at the seat of excitation will necessarily be returned like an echo to the other end of the line, acting upon the muscle in which energy is utilized, and the increase of muscular contraction will be the physiological expression of this echo in the muscle of the signal given by the sense impression.

Every diminution of potential, arising in a limited region of the nervous system, must thus be propagated from point to point, until equilibrium of potential be established throughout the whole system. This consideration connects itself with the mode of looking at the nervous centres which has already been explained.

When the senses are at rest, during sleep, as long therefore as nerve conductivity is on the other hand diminished, the difference of potential between the poles of the battery will attain its maximum. The condition least favorable to communication between these poles will exist, and the mechanism of utilization or expenditure will present itself in the state of minimum output.

This state of things corresponds, as in the ordinary voltaic battery, to a minimum of activity and the lowering of the standard of production of energy. It is the unity, or number 1, of the calculations of Helmholtz and Hirn.

Any impression whatever, communicated to an organ of sense, and transmitted by its nerve, will then render the circulation of electricity more active in the corresponding part

of the system. Multiplied impressions bringing about a recurrence of this activity, the total amount of oxidation will be increased, and the reign of wakefulness will be established.

Let new excitations now present themselves during the waking state, there will be, on the same principle, a still further increase of activity, so that the output of energy having risen from 1 to 4, by awakening of the senses, it will rise in the condition of full muscular activity from 4 to 5, to 6, or to 7, which appears to be the maximum usually observed.

Such are, Gentlemen, in condensed form of statement, my theoretical ideas on the structure of the living motor and on its manner of working. It is these ideas which I wish to see first submitted to experimental verification.

III.

THE MECHANISM OF VITALITY.

§ I. Of the characteristics of vital activity.

Having thus pictured to myself the conditions of the working of the nervous system in a living animal, working which is dependent upon the distribution of electric energy generated by physico-chemical reactions in the protoplasm, I have been led to examine how it is possible to conceive of the origin of vitality in this system, that is to say the origin of the reactions producing electricity in the very heart of the primitive protoplasm.

Reasoning from one inference to another I have come to propose in definite form the following thesis:

"Life is essentially characterized by the existence of a system of continuous reactions, the necessary elements of which are ceaselessly reproduced, and which take place in the midst of an appropriate medium.

"It presents itself to us, therefore, not only in the complex organism, but even in the last result of its structural subdivision, in the single *cell*, in which it still exhibits the same essential character by which it sufficiently makes itself known.

"It is not limited by particular morphological conditions; organic form and structure may vary almost endlessly with the condition of the medium, without the essential character of vitality thereby disappearing."

In order that this vital reaction may take place, three general conditions are necessary: first, the simultaneous presence together of the prime materials *essential* to the reaction: secondly, a particular state of distribution of these prime materials, from which may result the heterogeneity indispensable to the progress of the reaction: and, finally, such arrangements as shall permit the energy liberated by the reaction to be consumed, utilized or transformed, either on the spot, or outside the field of the reaction.

§ II. Of oxidation in the organism.

Among the chemical phenomena, varied as they are, which the living organism presents to us, there is one, that of *oxidation*, which is distinguished from all the rest by its generality of extent and its preponderant importance; we may even say that, so far as the higher animals are concerned, oxidation is

the essential chemical phenomenon of life, and the others are but of secondary character.

Besides, however this may be, any such distinction has but little importance from our point of view, since we have but to consider the presence of any two substances, one of which is electro-negative in relation to the other, and the liberation of electricity which results from their combination.

In making use then of the term oxidation, with a view to simplifying our language, we shall in no way reduce the range of our conclusions.

With the same object in view, Gentlemen, may I be permitted in what follows, to sometimes use an affirmative form of expression instead of one implying doubt, even when dealing with more or less hypothetical statements needing demonstration; you will thus follow me more easily, and it will be easy for you to assign its true scope to this form of statement of my views.

The principal seat of vital activity is to be found in protoplasm submitted to the action of oxygen. It is protoplasm which forms cells; it is by it that they live, and are nourished. As for the protoplasm itself, it derives its material from the various forms of food, solid, liquid and gaseous, which are thus the prime source of the energy developed in the organism.

If we try to explain how the protoplasm can play its part of generator of energy, we recognize at once that it is not alone sufficient for the generating prime materials to come together in order that the phenomenon shall occur.

This inevitable remark shows us, so to speak, the very central knot of the question, and may serve as the starting point of our further reasoning.

But, before broaching the subject of chemical change as it occurs in the organism, let us first consider a simple phenomenon and one with which we are familiar; we shall thus make clearer the statement which is to follow.

When we plunge a piece of perfectly pure and homogeneous zinc into acidulated water, as long as the metal remains isolated in the liquid we observe no reaction, save that at the first moment of introduction a difference of electric potential is immediately established, but all is limited to this.

If on the other hand we connect the zinc with the acid by a substance less oxidizable than this metal, immediately an electric current is set up and reaction between zinc and acid takes place.

Simple contact then does not suffice to bring about reaction; it can but produce a sort of orientation, of tension, or, if one please so to put it, a new state of equilibrium of the particles, in which there come in an electromotive force and a counter-electromotive force equal and opposed thereto.

When the circuit is completed by means of a non-oxidizable or less oxidizable substance, this equilibrium is made an end of, by doing away with the counter-electromotive force as a path of escape is offered to the electricity.

But the electric flow or current thus established constitutes an available form of energy, which may be used to liberate zinc if we cause such current to act, by a suitable arrangement, upon an easily decomposable zinc salt.

On condition then that we provide, by a supply of supplementary energy, for the inevitable losses of efficiency resulting from these successive operations, we see that it is possible to form a cycle of reactions corresponding at all points to our definition of vitality.

If then this definition gives a true statement of the facts, must we not come to recognize in the *vital cycle* the reproduced image of that which we have just sketched.

For my own part, I feel convinced that this may well be so, and I propose to induce you, if I may, to share this conviction with me, by showing you that we may interpret in a way favorable to the conclusion before us the chemical phenomena of life.

Let us consider a culture medium capable of maintaining the life of a given cell by furnishing it with all the constituent material it requires; and let us observe that in order to suitability of the medium for the cell the former must contain *at least* all the chemical elements which occur as constituents of the latter.

As long as the cell is absent, this medium may be compared to the voltaic battery with circuit un-closed, which we have taken as example by analogy; like this latter, and by virtue of the same natural laws, it will present a state of equilibrium due to the existence of two opposite electrical forces—a kind of state of *virtual combination* between the electro-positive and electro-negative constituents—but no chemical change will disturb its original homogeneity.*

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* Chemical reactions and physical phenomena of the kind attributed to cohesion are due, according to our notions of physico-chemistry, to the electrical condition of the particles in presence of each other, their difference of electrical condition being precisely that which constitutes *affinity* or *attraction*. These reactions and phenomena lead then, as a physical result, to the setting free of a quantity of electricity corresponding to the several differences of electric state. Hence it is plain that, if this electricity be directed upon new particles ready to combine with each other, it may counterbalance their affinity, and

Let us now suppose that the living cell is introduced; as soon as equilibrium is overthrown, displacements of electricity are set up, combinations and decompositions take place, and the vital circulation of energy and matter is established.

To explain what has thus occurred, we must assume, it seems to me, that the first result of the introduction of the living germ or cell has been to offer to the electricity conducting paths, or, in other words, to bring about what I will call *odogenesis*.* The first effect of vitality would seem to be that of a contact action, allowing of chemical change being energetically produced by favour of the short circuits offered to the electrical energy engendered.

§ III. Of the part played by the living cell.

Nevertheless, how can this take place, since the medium we have under consideration continues inactive, the cell introduced reacting only with the stratum of this medium with which it is in immediate contact?

To explain this, it is essential to remark that, from the quite special point of view at which we are just now placing ourselves, we must logically think of the cell as chemically forming a part of the medium by which it is surrounded, since it draws from thence, and continues to draw from thence, the materials of which it is made up. The cell, although

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consequently prevent their movement and arrest reaction between them; this is what happens in the case of pure zinc and acidulated water, which, so to say, form what I have called a *virtual combination*, and this is also what may happen in the case of the inactive organic medium which we are considering.

* Odogenesis, the creation of a path, from ὁδός and γένεσις.

distinct from the medium, is but a fraction of it. The chemical medium thus extends to the cell which lives in it; the latter in finding its way into the former has but set up a *selection* among the constituent elements.

The fundamentally electro-positive materials go to form the substance of the cell itself; the oxygen, or its electro-negative equivalent, remains in the portion of the medium which is in intimate contact with the matter of the cell, whether on the outside or on the inside of the morphological element which it constitutes.

It follows then clearly from this remark that the cell is, properly speaking, but a *means of reaction* presented to the medium, and, further, that the path for electric conduction that we are looking for must exist between the cell and the fractional part of the medium, which is in direct relation with it.

§ IV. On the part played by selective electrolysis in the phenomenon of cell nutrition.

But, before we concern ourselves with this point, we ought to look into the phenomenon of cell nutrition, and ask ourselves how it is that, in the complex medium that surrounds it on all sides, the cell is able in some way to choose the elementary particles which suit it; by what directive influence these particles take up their positions and arrange themselves in such a way as to become integral parts of an organized structure; whence, finally, comes the impulse which determines the *special course* of the vital circulation of matter and energy, allowing the cell on the one hand to assimilate such or such a determinate constituent from the medium, whilst, *at the same time*, it gives up on the other hand some constituent which has just before formed a part of its structure?

It is easy to reply to these questions if we go back to the inorganic reaction between zinc and acid, and take it as a new subject of comparison, imagining now the zinc to be in a finely divided condition. We have seen that in this case the acid, ready to combine with the zinc, is held in check by the electricity set free at the first moment of contact, this electricity counter-balancing or neutralizing its chemical affinity.

We have the same state of things before us in the growing cell surrounded by a nutrient medium; the albumenoids of the plasma correspond to the finely divided zinc; the oxygen represents the acid of the mineral illustration.

When this oxygen, kept in the inactive state by favour of the albumenoids with which it is virtually associated, makes its way with them into the domain of the cell, and comes in contact with albumenoid materials of the same kind, but more readily oxidizable for reasons which we shall see further on, it at once enters into combination with them. It thus sets free new portions of albumenoid matter from the virtual combination which it had formed with them; and these immediately take advantage of the electricity produced by the oxidation to raise their own electric potential to such a point that they may be able, in consequence, to take in turn their places in the structural edifice of the cell thus endothermically built up.

It is in this way that, quite naturally, the cycle of reactions is established which constitutes the rotation of changes in the living machine.

The mechanism which we have just explained shows how the chemical changes which represent the nutrition of the cell take place in the inmost recesses of the living substance itself, from atom to atom and from molecule to molecule,

producing, in place, the electric energy needed for each ensuing reaction, and step by step with its occurrence.

Following out this order of procedure, the cell may be said to withdraw from the surrounding medium the nutrient materials which are adapted to the different points of its own substance, by its proper affinity, which I will call *power of selective electrolysis*, but which is merely the resultant of the previous electrical condition of the constituents concerned. The dropping out of the one constituent necessarily incites the re-entrance of another precisely similar constituent. Thanks to the continuity of the rotational change going on, each particle of the cell passes in succession, all other things being equal, through the same phases of condition with that which has preceded it, from the moment of its admission to the substance of the cell up to the moment when it becomes separated from it. Before being introduced into the substance of the cell the atom must leave the *virtual combination* in which it was held. It is precisely the disappearance of the atom which precedes that furnishes to the one which follows it the exact amount of energy required to effect its *selective electrolysis* or its liberation from the state of virtual combination. Thus we shall have concordance, referring to the possibilities of the case, between what the one lacks in order to leave the medium and enter into the substance of the cell, and that which the other provides when it frees itself from the combination in which it has been held in order to engage itself in one more powerful; and, on the whole, quantitatively speaking, there will be a certain available excess of energy on the latter side. It follows from this that the points of accretion, howsoever distributed as to position in the protoplasm, always retain their identity both in composition and

structure; and, as the same causes everywhere bring about the same effects, the whole cell must reproduce itself indefinitely, with maintenance of its identity, if the nutrient medium on its part remain constant in character and the process of transformation go on.

§ V. Of the part played by dioxyasthenia in the phenomenon of cell nutrition.

In order to finish this statement it remains for us to speak of the cause of greater oxidizability, which we may call *dioxyasthenia;** this will also allow of our returning to the question of odogenesis.

This cause, it seems to me, is found in the circumstance that the rotational series of vital changes involves, as a necessary consequence, the simultaneous existence in one and the same cell of both *new* and *old materials.*

The latter, in fact, longer exposed than the former to the repeated attacks of oxidation, must exhibit less stability; they are in some sort prepared, by their age, and by the influences tending to change and breaking up to which their molecules have already been subjected, for the oxidation which is about to attack them. The newer parts, on the contrary, for opposite reasons, survive the older; they it is which furnish the odogenic materials and the paths for conduction which we have already discussed, and it is they which must ensure the continuity of reactional activity.

With a higher degree of complexity, the living cell in fine is used up and renewed like a crystal.

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* That is to say: without strength against oxygen.

The parallelism is so striking that one might be tempted to say of the crystal, which retains its nature and all its peculiarities of structure in spite of the constant renewal of its material, that it is endowed with a sort of *mineral life.*

§ VI. Of the evolution of vital activity.

Vitality exhibits, moreover, all degrees.

If it is characterized by continuity of activity, and constancy in the regeneration of substance and structure, in the case of those living beings of which the cell activity is exhibited to us in visible, evident form, this is no longer so in regard to organisms in which the most patient observation cannot detect any activity, such as some of the inert rotifera and tardigrada, or such as spores and ova. In these activity is suspended or impeded; life, if we may still use this word to represent such a state of things, is absent or reduced to its minimum.

The preceding hasty sketch sufficiently shows, I think, that it is legitimate to compare, as I have done at the outset, the mechanism of vital activity to that of a single element of a voltaic battery, when once we recognize in the living cell the special part which I have assumed it to play.

It seems to me that the analogy between these phenomena is too close, the parallelism too persistent, the comparison too natural and too easy, for the conclusions which may be drawn from thence to be illusory.

And what, besides, is this odogenesis but a special case, in the chemistry of the living organism, of the general phenomenon which we observe occurring both in the so-called *contact actions* or *actions by presence* of mineral chemistry,

and in the cases of splitting up by *soluble ferments* of organic chemistry.

To my mind these three orders of phenomena form but a single one, which may be rendered intelligible by the idea of *paths for electric conduction.*

Life, which results from the reaction between the external medium and the internal substance in which it is manifested, is characterized by the fact that it is in the organism the reaction takes place; it is also for the benefit of the organism that it occurs, since the living being grows and reproduces itself.

Life will thus represent the last stage of a course of physico-chemical evolution of which the starting point is to be sought in the so-called contact actions.

In mineral media, in which reactions are simple, the first term of this series of phenomena is represented by the part played by substances which come in to bring about or facilitate a reaction, without themselves being used up or consumed. As more advanced terms in the same series we must regard those substances which, playing this part of intermediary, are nevertheless to some extent modified by the reaction, such as the zymases or soluble ferments. And we must consider as the ultimate term living beings, which gradually engrossing more and more the reaction which they bring about, are the more and more perfected consumers or utilizers of the chemical action which they induce. In the first instance the reaction occurs in the medium, and later, gradually, it comes to be localized in the living being fitted to sustain it.

Just as we have seen, in mineral chemistry, the giving up of the hypothesis of *catalytic force*, which no one now-

adays will defend, so we shall see disappear that of *vital force*, the memory of which will hereafter serve to characterize the present period of investigation.

I believe that these general considerations will suffice to render intelligible, and in a provisional way to justify, the mode in which I conceive of the mechanism of life, with the aid of the physical and chemical forces of nature only, and without invoking any mysterious or extra-natural cause.

I ought from now on, it would seem, before entering upon the path of new experimentation, resting only upon already ascertained facts, to develop the several parts of this subject, but I think it preferable that I proceed by degrees and restrict this mere programme to its true character, laying aside for the future, and if a suitable occasion present itself, the treatment in a more thorough manner of points which are now but touched upon or even passed over in silence.

I cannot, however, excuse myself from broaching a few of the points in physiology which depend directly on the principles which we have had under discussion; to do otherwise would be scarcely logical, for this would be to lose all the advantage of a preliminary trial of a new principle, such as may be made, in advance of any experimental attempts, by investigating on the one hand how far such a principle may lend itself to the explanation of facts as yet ill known, and on the other hand whether it be not contradicted by some well established truths.

IV.

OF REPRODUCTION AND EVOLUTION.

§ I. Of fertilization.

Keeping still in the same line of thought as before, we may say that a germ not as yet fertilized—egg or seed—may be compared to a culture medium, and that to fertilize an ovum is simply to introduce into it materials, chiefly old, derived from an anterior but similar cell protoplasm, suited to set up in it the reaction necessary for its evolution; the ovum thus appearing to need the older, and the spermatozoon the newer material in order to be able to sustain the living condition.

It is sufficient here to apply what we have already said in regard to the life of the cell, and of odogenesis, to understand how the spermatozoon brings about, by its difference of nature, the reaction in the ovum and the establishment of paths for electrical conduction.

I will add that it is natural to assume that the intensity of the first impulse produced by the intromission of the spermatozoon is a function of the qualitative character of the material which it supplies to the ovum.

The latter will be the seat of reaction so much the more perfect that the male element shall have supplied it with more appropriate material, exhibiting a more complete condition of maturity.

It is by the greater or less preponderance of the male and female elements respectively that an explanation may be

found, I think, for the congenital inequalities which, aside from all other circumstances, influence the development of the embryo.

And even if it be true that in the higher species of animals the male usually presents a more advanced degree of development than the female, and therefore lays claim to a greater sum of dynamic energy during the period up to the middle of life, I ask myself whether we should not see in the variability of original impulse a principle of explanation for the difference of sex.

§ II. Of growth and proliferation.

We have said, in speaking of the round of vital changes, that the cell, while remaining alive, may increase, decrease, or maintain a stationary condition, according to certain circumstances. But it does not seem to me doubtful that the chief of these circumstances must consist in the relation in respect to composition which exists between the cell and the medium which is presented to it.

As proliferation must necessarily correspond to a state of more than adequate nutrition, in order that this phenomenon shall occur the medium must, in the first place, be superabundantly provided with the material which the cell demands.

But these chemical conditions alone would but suffice to increase indefinitely the size of the cell; in order that it may undergo proliferation, whether by direct or indirect division, a physical cause must besides come in to modify the *conformation* in a continuous way. But I believe that this cause is nothing but the existence, in the very heart of the cell, of *directions of least electric resistance*, which are consequences of its mode of molecular structure.

The present state of our knowledge does not yet permit of any theory being propounded on this subject, but I do not find it possible to view the disaggregation and grouping of the molecules of the cell in course of proliferation as unconnected with the action of electrical energy.

Considering here only the physical reason for the phenomenon of cell reproduction, and not aiming further to apply it to any particular case of division of the parent cell, it seems to me certain that in its inward mechanism the act of division comes back to a question of unequal oxidation and nutrition—hence of varying development—at different points of the cell. And under these conditions we shall have to place the phenomenon in question in relation with the unequal conductivity of the different parts of the protoplasm in order to find its mechanical reason. We need then but know the constitution of the protoplasm in regard to the varying resistances which it presents to be able to define the part played by electricity in this phenomenon.

I suggest this idea merely to call your attention to the question, and to show that we may, as it seems to me, find in the principles which I have put forward the starting point for the explanation of the inmost phenomena of life.

§ III. Of the chemistry of protoplasm, and of evolution.

As for the phenomena of life, so for the transformations of *species*, we cannot, in my opinion, acknowledge any other causes than the physical and chemical forces, ever modifying their manifestations, and bringing into existence different types according to the variations in condition of the medium.

If it be true to say that the life of the individual is absolutely dependent, in all its manifestations, upon the chemical

constitution of the individual protoplasm, we may assume that the special characteristics of particular zoological groups are but the expression of the chemical peculiarity of their protoplasm. Many circumstances, in fact, lead me to believe that morphological differences which seem important will admit of explanation by very minute variations of composition in the chemical structure of the protoplasm, and in the order of association of its constituents, under the influence of the conditions existing in the external medium.

To understand this point it is necessary to look carefully at the protoplasm, and to consider it in the reproductive cell.

We may assume—and ascertained facts in this very complex field of science do not, I think, run counter to the idea—that the chemical composition and molecular grouping of the fertilized ovum, with the *selective electrolysis* which must subsequently occur in it under the action of external causes, are sufficient to explain the progressive transformation of the egg.

Each egg presents characteristics of its own, and brings into existence a special individuality. We may consider it as a true *animal molecule*, which corresponds to the cell constituents which have given it birth, and to the precise conditions of the medium in which it has been engendered.

The exact chemical composition of the protoplasm, along with the action of the external medium, must, in my opinion, alone be capable of explaining completely the structure and the form of the cell and of the organism, as well as their inherent tendencies.

This chemical composition of protoplasm is as yet unknown. To succeed in understanding it, or at least forming some idea of it, we may consider the constituent albumenoids of

protoplasm, not as sharply defined compounds, distinct one from the other, but rather as being, in the aggregate, a single fundamental substance, a single albumenoid, of which the complexity may vary almost endlessly under the action of a foreign constructive energy. The occurrence of these variations in the molecule will be due to the successive joining on, in an order which may vary greatly, of secondary or connecting ingredients, which will have the effect of each time fixing in the molecule new quantities of the primitive radicle. This latter then will occur in the complex molecule in proportion to the number and quantity of the secondary elements or ingredients.

If this conception cannot be adopted, we shall have to imagine that the primitive radicle may combine with some one of the secondary ingredients, in equivalent quantities, within very widely extended limits, to form each time a distinct variety of albumenoid. Foreign constructive energy will then associate together, in an order which may be almost indefinitely variable, the molecules of each of these albumenoids. Thus shall we have protoplasm built up.

In the one case as in the other, if we take account of the important number of secondary ingredients which may enter into the constitution of protoplasm, we reach the idea of what we may be tempted to call the *general albumenoid molecule*, extremely complex in nature, extremely bulky although within definite limits, and almost endlessly variable, as well in the arrangement of its constituent parts as in its external form. This general albumenoid molecule will be the true animal molecule, that is to say the *theoretic animal cell.*

It must be assumed that such a molecule will possess in

all its parts the degree of homogeneity generally attributed to complex chemical molecules, neither more nor less.

But let us suppose that oxidation takes place slowly and regularly, according to rule and method. Heterogeneity soon manifests itself; vacant spaces are formed, occupied spaces remain, in a well determined order which depends of necessity upon the inward constitution of the general molecule. We see in this way morphological characteristics come into existence; we thus obtain the cell as we actually know it, differentiated as greatly as may be its chemical composition, stable from the morphological point of view as the supply from the medium may be constant of material for reconstruction.

The cell, it may be said, is the *general albumenoid molecule* assailed and partly broken up in the beginning by oxidation, but ever seeking to completely reconstruct itself, without ever succeeding in doing so.

To each living being, to each organ, to each variety of tissue, there corresponds such a *theoretic animal cell*, in which the slightest variation in excess or in defect, even though it be but local, of one of the constituent biogenic substances will bring about a more or less important modification of the form, of the organization, of the properties of this cell, and consequently also of the characteristics of the living being, of the organ, or the tissue to which it corresponds.

The richness of a particular protoplasm in oxidizable material will be the essential factor of the energy which it can liberate.

If there be acquisition of new secondary constituents we shall have before us an evolution, which may be entitled progressive, though there should not be attached to this word

any other meaning than that which the essence of transformation gives it.

The very method of cell proliferation, which proceeds by division of the protoplasm, requires in addition that the modifications which may occur shall be produced with great slowness and by the most gentle transitions. There must of necessity be almost complete continuity between the cells of the same living being, from the chemical as well as the histological point of view, if they be regarded as forming a direct line which starts with the ovum whence they all have been derived.

Let us consider cell proliferation during the embryonic period of existence of the individual. The nascent cells are chemically identical with the structural elements from which they are derived. It is only during the period of their growth and of their completion that these cells can change their constitution and structure by reason of variations of the medium in which they live. But, if we study this medium in its relation to each cell taken separately, we see that its value cannot remain constantly the same.

It must vary, in fact, in proportion as the cells already formed have taken away from it certain constituents more especially than others. The medium thus gradually becoming impoverished as regards certain substances, the nascent cells must accommodate themselves progressively to the new conditions of nutrition. Thus is brought about in the embryo the chemical evolution of new modifications of cell protoplasm.

In regard to the degree of complexity of protoplasm, we may assume as eminently probable that the forms of protoplasm which hold the highest rank in the order of evolution

are precisely those which possess the most complex internal structure. The molecular constitution of a protoplasm will, therefore, be a witness to the transformations which the species has undergone in the course of ages, an index to the duration of the period of evolution which has been traversed since the origin of living beings.

The general tendency of the science of the present day is to assume that the different forms of protoplasm resemble each other or are even identical throughout the whole series of living organisms. As I have already said, infinitesimal differences may here be of great importance, but the difficulties of analysis are such that in this line of thought there is a whole array of problems of which the solution by experiment may perhaps never be attained.

To bring differences into existence, and to part off distinct varieties or species, the joining on or the increase of secondary constituents is not indispensable.

A variation in the order of grouping of these constituents, and consequently in the molecular structure of the protoplasm, such as may be produced by prolonged or repeated physical influences from without, will suffice to differentiate two living organisms. Do not certain organic substances, identical in per-centage composition, possess different physical and chemical properties by reason of differences in structure such as we indicate by their formulae? It will be the same thing in the case before us, so that, on the whole, the causes of diversity will be, the original proportion and order of grouping of the constituents, and the subsequent modifications brought about, under the action of external causes, in this same proportion and grouping.

Every modification of the nature of those we have been

suggesting will represent an acquired status; that is to say, it will tend to maintain itself, to persist by reason of the very fact that it has once been realized, and, as generation is but a subdivision of the generative protoplasm, when this has once undergone such persistent modification, the modification may be transmitted by heredity.

Hence it will suffice in some cases that a modification be once strongly impressed, that a combination be once achieved, sometimes even that an accidental predominance once occur of such or such an essential ingredient in a given protoplasm, in order that a new individuality shall make its appearance.

The infinite variety of combinations which may be produced by the play of the numerous ingredients of protoplasm explains, in my opinion, the existence of the infinite variety of living beings, and the influence of acquired status enables us to understand how these combinations, once realized, may affect not only the individual, but the race, and the entire chain of evolution.

Finally, this same influence of previously acquired status enables us still further to see how two organisms may be made up of protoplasms of the same per-centage composition, and yet differ much from one another.

Thus, let us suppose that an originally rich protoplasm continues to become impoverished by the loss of certain of its constituents, whilst a poor protoplasm undergoes evolution in the opposite direction by successive gains of like constituents, it may be that at a given moment these two protoplasms may have the same elementary chemical composition, and yet may differ by the whole import of the structural states which they have previously passed through.

It may be said then that the comparative chemistry of

living tissues will allow, like its elder brother, general chemistry, of cases of isomerism, polymerism, isomorphism, etc., on condition always that we give to these terms the special meaning which their physiological acceptation implies.

V.

OF PSYCHICAL PHENOMENA.

§ I. Of the part played by sense impressions. — Origin and functions of nerve *anastomoses* or *ganglia*.

If it be true, as I have said before, that the sensory organs constitute a regulating apparatus which determines in due proportion the amount of vital oxidation in accordance with the stimulations supplied by the environing medium, and if on the other hand the genesis of energy induces by selective electrolysis a fixation of organic ingredients in the very regions where the reaction is effected, shall I not have a right, Gentlemen, to conclude that every impression modifying the current through a nerve is reflected back upon the muscle by the interposition of the nerve centre, and determines a variation in oxidation and in deposition, no matter how small, which is a function of the stimulant impression. This variation, with positive or negative sign, will be in some sort the material representation of the effect produced by the impression from without; every sense impression will re-echo in the end upon the muscle.

The impression will not only give rise as its result to a selective electrolytic change, but, further, it will affect the nerve

ganglia, that is to say the inter-communications among the nerves by which electric energy has been distributed; for we know that in order to reach the muscle, starting from a point which has been the seat of sense impression, it has been necessary to pass through some nerve centre, it may be through the brain.

There is nothing in fact to show that certain nerve ganglia may not be created by the necessities of such or such a transmission of electrical energy. This may be the case if the nerve cells possess a sort of plasticity, such as we have already spoken of, and by virtue of which, under the influence of electric attractions due to differences of potential between adjacent parts, communications will be established between them, more or less temporary or persistent, more or less strong, more or less numerous, and more or less uniformly distributed or localized.

This genesis of secondary paths of conduction ensures the maximum utilization of electrical energy.

It is above all during the first stage of development of the organism that there will be produced, slowly and gradually, these anastomotic connections, as direct consequences of the development, and hence of the more or less strongly marked impressionability of the senses under the influence of external physical agencies. In their associated aggregate these anastomotic relations will at all times correspond to the general condition of intellectual and physical education of the individual at the moment, and there will hence result a general condition of apportionment and a general distribution of potential corresponding with the standard of nutrition of the tissues of the electrogenic apparatus.

Even in the embryo this will be the case.

So that, from the moment of fertilization to old age, electrical energy, helped or hindered by outside activities influencing the organism and modifying its normal conditions, will seek for its own better or easier utilization. In this will be found the first cause of life, of cell proliferation, of the genesis of nerve and muscle, the cause of the development of the single organism and the evolution of others, and equally the cause of the existence of a psychic process and state.

The repetition of the same impressions, strengthening and increasing their first effect, will give rise, so to say, to a permanent organic modification, and this may go on, in the light of evolution, even to the production of special types more peculiarly receptive of certain classes of stimulations.

§ II. Of the mechanism of memory and thought.

As soon as this organization becomes realized in any individual, the bringing into play of the special nerve mechanism need no longer necessarily depend in an immediate way upon an external cause; the individual is capable of receiving, under the influence of the slightest stimulus, even though internal, an impression which corresponds to a former stimulation, without actual renewal of the original material irritation itself; from the time that the special structure has been established, whenever the organism passes again through phases of condition nearly the same with those produced by a stimulation which has left its trace behind, this organism *will remember*.

If the new impression be *identical*, in every respect, with that caused by a previous excitation, remembrance in the proper sense of the term will not present itself. "*Memory*"

must be considered as a combination of former stimulations almost accidentally renewed with new stimulation of the present moment and of a different kind: the idea of "*time*" would be lacking in a being whom we may imagine, either incapable of excitation, or continually receiving absolutely the same impressions, both internal and external.

As for "*thought*," this will be the infinitely variable result of former or mediate excitations, combined with one another, or with new excitations of the present moment, whether of external or internal origin. By reason of the anastomoses existing between the cells of the nerve centres, one thought will call forth others, and so on, as if it were a question of reiterated external stimulation.

Each "*idea*" corresponds to a determinate mode of distribution of energy. There will be therefore as many different thoughts as there are different conditions of general distribution of energy.

Such are the relations which exist between the structure of the brain and intellectual phenomena. But we must not consider this structure as pre-established; it is the consequence of the sensory stimulations which have determined variations in the products of selective electrolytic deposition, whether in the nerve centres or in the muscles of the individual or of his ancestors.

§ III. Of epaphy.

It is needless to say that there will not always be formed even momentary anastomoses corresponding to all kinds of stimuli; if these latter be fugitive in character, if they address themselves to regions of the brain already actively at work, and of which the nerve cells or their prolongations are in the

immediate vicinity of each other, even though not touching each other, there will be established more or less strongly marked contacts, analogous to those of the microphone, and we shall still have in this way all that is needed for a true physiological impression. If we apply the term *epaphy* (ἐπαφή—contact) to this kind of contacts, we shall have impressions or states of ganglionic distribution and impressions or states of epaphic distribution of energy. In either way, to each impression there will always correspond a general condition of apportionment of the amount of muscular nutrition in the electrogenic apparatus.

The importance of the nervous ganglia, assuming for them the part which I have suggested, proves to me that it is not in the weight or bulk of the brain is to be found the measure of the intellectual strength of an animal or a man, but that this depends upon the force or importance of all its activities.

For an equal weight of brain, the inequality between one individual and another will depend upon the number and character of the nervous anastomoses and epaphic contacts existing in each, a number which must itself be related to the more or less numerous cell approximations existing, or capable of existing, in the brain; these latter will be so much the more numerous as the total development of surface of the gray matter is more notable. If such a relation really exist between the number and character of the nerve ganglia on the one hand, and on the other the surface presented by the convolutions, it is clear that the degree of intelligence of the individual may be expected to correspond with the development of these cerebral convolutions.

§ IV. Of the relations existing between organic and psychical functions.

The considerations just brought forward, in addition to the physiological considerations previously before us, lead us to apprehend the existence of a close parallelism, both in the scale of animal life and in that of embryonic development, between the growth of a part of the muscular system, that of the sensory nerve network, and that of the intellect. These three things must be looked upon as connected, entirely interdependent, and each a function of the other.

The ganglionic network of the great sympathetic system may in strictness be considered as the true representation of a subordinate or reflex psychology, if we may thus express ourselves. The cerebral network of ganglia appears as that of the higher or intellectual psychology, originating primordially from the sensory excitations. By investigating which are the tissues corresponding to the nerve ramifications from the organs of sense—and it seems that they are to be found chiefly in those which, extremely slender and finely divided, serve to express the emotions—we shall get hold of the part of the electrogenic apparatus corresponding more especially with the psychic faculties.

We arrive then, by this line of thought, at unity between the organic and the psychical functions, and this unity asserts itself moreover strongly in the analogies between reflex and voluntary actions.

§ V. Of reflex and conscious action.

What difference is there, in fact, from the point of view of the inward mechanism concerned, between a reflex act and a conscious act.

We may reply that there is none. Neither the one nor the other of these acts is free; the same invincible necessity of

physical and chemical law binds them to the reaction of the organism as a connected whole. It is always to the advantage or to the detriment of this reaction of the whole organism that the partial reactions are effected, whatever these may be, and wherever may be their seat.

Between the most conscious act, such as I perform in communicating to you my ideas, and the purely reflex action of my heart, which beats without my knowing it, and regulates its own movement by a sort of automatism, there are to be found gradations, in an undefined series, and with insensible diminutions of consciousness, of reflex and instinctive actions which represent the greater part of our activity.

What we call "*consciousness*" is the mere abstraction—in default of terms with positive meaning we make use of those of hypothetical or metaphorical character—which corresponds to the resounding in the whole electrogenic apparatus of the impression received, or the act performed, by one or more of its parts.

The whole suffers the consequences of the action which takes place in the part, since the whole and the part are intimately linked together and in partnership, but the electrogenic apparatus bears sway over any one of its parts by all the difference of functional importance which exists between them; in its entirety it constitutes the perfected "*living being*," "*sentient*" to influences from without, which cannot be other than of a physical kind, and which have gradually "*endowed*" it with "*motivity*" and "*activity*." Thus it "*feels*" in proportion to its importance or its perfection, and to the relative organic force of the impression received. That is to say, it "*compares*" and "*measures*" a fact, or it "*estimates*" and "*judges*" an act performed.

The electrogenic apparatus has the "*power*" or the "*faculty*"—which means that it has as its "*mission*" or "*function*"—to "*act*," if it be "*urged*" to do so by a stimulation from within or from without. It acts then *under compulsion*, unless it be that other sensory stimulations, internal or external, such, for example, as those which induce "*volition*," come in to counterbalance the influence of the former.

What has been called "*free will*" is nothing but necessitated action lost sight of in the complication of conditions; it is the invincible compulsion of the physical and chemical laws of the organism working amid actions to which they have already given rise—that is to say, in the midst of the immense store of facts, of thoughts, of ideas, and of sensations long accumulated, from which there comes forth our last thought or our last action.

This inevitable necessity is in us so attenuated that it is hard to follow up its lines and recognize its traces, but it is always the expression and the result of these natural laws; it is always a necessity.

The statement which I have now laid before you, condensed as it is, will no doubt suffice to make you acquainted with my deductive views; I do not conceal from myself, Gentlemen, that, to do justice to my subject, each of the points I have aimed to present to you should have been more precisely stated, more dwelt upon, and more fully developed; I hope that, to the extent of my ability, it may be granted me to return to the subject.

I await now as the result of the most rigorous course of experiment, pursued in the broadest and most extensive manner, an impartial and thorough examination of the scheme which has been the subject of much of my thought for so many years.

I sincerely thank those among you who have kindly aided me by their knowledge and their advice for allowing me thus to formulate the physiological theory now before us.

One word more, and I am done. I have highly appreciated the evidences of gratitude which have been conveyed to me by the Burgomaster and the Council of Aldermen* in the name of the City of Brussels; but I cannot accept their praise. I have not the good fortune to be a man of science; I have not received a classical education; industrial problems have absorbed my time; but it is true that I have not ceased to pursue a scientific aim, because I love science, and I look to it for the progress of humanity.

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* See the Appendix, page 71.

APPENDIX.

LETTER

addressed to the Administrative Inspector of the University.

BRUSSELS, *20th May, 1892.*

To the Administrative Inspector,

Sir:—The special Commission appointed by resolution of the Administrative Council, with a view to giving advice on the subject of extending the buildings of the Faculties of Science and Medicine, has come to the conclusion that it is necessary to build, apart from the existing premises of the University, at least three Institutes to be assigned to the Faculty of Medicine, and to devote the present premises, thus vacated, to extensions called for by the needs of instruction in the department of general Science.*

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* This Commission was composed of MM. BULS, GRAUX, VANDERKINDERE, DEROUBAIX, STAS, HEGER, and STIÉNON (18th July 1891).

These decisions are in conformity with the wishes of the Faculties concerned. They tend to place our instruction on a level with the educational advances made abroad, and at the Universities of Liège, Ghent, and even Louvain, by means of laboratory work.

The carrying out of such a scheme may be long delayed if there be not secured for it the active and efficient intervention of all those who share the belief in its desirability.

In accordance in this respect with what has engaged my thoughts all my life, I desire now to offer you my personal assistance for the realization, with little loss of time, of a part at least of the DESIDERATA *above mentioned.*

I will devote the sum of two hundred thousand francs to the erection of an Institute of Physiology and the completion of the scientific equipment at present employed in the teaching of this science.

The buildings will be erected under my charge in the Leopold Park, close by the Solvay Institute, which I expect to have built there.

It will be, from now on, the property of the City of Brussels; its appropriation to the purposes of the University Institute of Physiology will be maintained by the Administrative Council, which will have the use of it.

Before carrying out negotiations with the City of Brussels in regard to obtaining the necessary land, I wish to know whether your Council is disposed to accept the above named gift, to which I attach the following conditions.

The internal organization of the two Institutes is to be absolutely distinct the one from the other.

They are both to be presided over by Professor Heger, but in case of a vacancy in the chair of Physiology the new incumbent,

appointed by the Administrative Council, is to become the Director of the University Institute, whilst I am to retain for myself and my legal representatives entire freedom in regard to the appointment of the Director of the Solvay Institute.

I express also the following wishes, but nevertheless do not make them conditions of my donation:

1st—The personal staff, both of management and of teaching, should be as far as possible the same in the two Institutes, in order to make them yield, as a scientific whole, the greatest amount of useful result;

2nd—There should be organized by the University, in the University Institute, beside the courses at present provided for by law, practical courses of instruction in physiological chemistry and medical chemistry, including electro-physiology. These courses should be obligatory, and followed by examination. Their organization should be such that they will allow all students of medicine to pursue the practical studies in physiology, especially from the chemical and physical point of view.

These steps have as their object not only to improve the university instruction in general; but also to train up a certain number of investigators, capable of devoting themselves to thorough work in the laboratory, and to allow of these select students carrying out physiological researches in a special laboratory of the University Institute.

The students thus trained in the practice of research, and doctors of medicine who have finished their studies, may afterwards find in turn at the Solvay Institute an opportunity to apply their knowledge to original researches of a more special character.

I will submit the plans for the University Institute to examination by the Administrative Council for its opinion and advice.

You will oblige me by laying my proposition before the Administrative Council with as little delay as possible, in order to settle matters in regard to negotiation with the City of Brussels.

Be kind enough to accept, Sir, the expression of my feeling of high respect.

E. SOLVAY.

The Administrative Council of the University having had this letter under consideration at the session of May 28th, 1892, unanimously determined to accept the proposal made by Mons. E. Solvay, and to refer the examination of the various questions raised by the establishment of the new Institutes to a special Commission appointed for this purpose.

At its session of June 4th, 1892, this Commission adopted the conclusions of a report to be submitted to the Council, in regard to the organization of the practical courses of instruction, and the duties of the personal staff of the University Institute of Physiology.

Certain questions were referred for examination to the Faculty of Medicine, which, at its session of October 7th, 1892, declared itself in favour of the designs laid before the Council.

On the other hand, as early as the month of June negotiations with the Communal Administration of Brussels had resulted in the drawing up of an Agreement which was submitted to the Communal Council at the session of June 27th, and of which the text will be found further on.

EXTRACT

from the minutes of the session of the Communal Council

(June 27th, 1892.)

MONS. BULS, *Burgomaster, presiding.*

Present: MM. Buls, *Burgomaster;* André, De Mot, Becquet, Janssen, De Potter, *Aldermen;* Depaire, Gheude, Doucet, Pilloy, Allard, Yseux, Richald, Kops, Steens, Stoefs, Bède, Brûlé, Heyvaert, Lepage, Goffin, Delannoy, Vandendorpe, Furnémont, Lemonnier, Levêque, Grauwels, *Councillors;* Dwelshauvers, *Secretary.*

INSTITUTES OF HIGHER INSTRUCTION IN THE LEOPOLD PARK.

The Burgomaster makes, in the name of the Corporation, the following report:

Science in its pursuit of truth constantly sees the field of its investigations expanding before it; it constantly resorts to more perfect, more improved means for sounding the mysteries of nature.

The method of experimental work and the specialization of studies have yielded admirable results.

But men of science have not been slow to recognize that, even when concentrating their researches upon an isolated domain of science, they cannot thoroughly explore it in all its parts without calling to their aid the investigative forces of the other departments of human knowledge.

Hence the fruitful progress which Johann Müller effected when he founded the Berlin Institute of Physiology, and when he called upon chemistry, physics, botany, mechanics

and medicine to throw new light upon his physiological researches.

We know what admirable conquests were achieved by such a general, who had as his lieutenants men like Purkinje, Schwann, Dubois-Reymond, Helmholtz and Brücke.

The results obtained were so brilliant that all the universities of Germany saw that if they would not decline in influence they must establish such institutes, and the example was not slow in being followed by England, France, Switzerland, Holland and Belgium.

These institutes do not serve only for scientific researches; they have brought about a reform in the methods of instruction of the higher education, analogous to that which has been pursued in primary and intermediate education, by the introduction of methods based on direct observation and experiment; they give the students an opportunity to ascertain for themselves the phenomena which they are taught; they place at their disposal well equipped laboratories, in which the pupils are called upon to work outside of the hours of lecture, and to acquire practice in the management of the apparatus of medical physics, and in the manipulations of physiological chemistry.

The time has come for the University of Brussels to place its instruction on a level with that of foreign universities, and even that of the Universities of Ghent and Liége, for which the State has built institutes on a large scale.

But our capital city has already assumed heavy burdens for the benefit of the University, and it might have been difficult for it to bring about this indispensable improvement of its higher education if the generous intervention of one of our fellow-citizens had not come in to level all obstacles. Mons. Ernest Solvay offers to the City of Brussels to erect at his expense two buildings intended to accomodate, the one, the Solvay Institute, already founded, and of which the proposed plan is to seek to determine the part played by physical agencies, and especially electricity, in the phenomena

of life; the other, the University Institute, in which practical courses of instruction will be given in medical physics and physiological chemistry.

The only condition which Mons. Solvay attaches to his generous gift is that the City furnish him the land without cost.

The Corporation has found an arrangement by which this condition may be met without its costing the City anything, and now proposes to you that a sufficient piece of ground be placed at the disposition of Mons. Solvay in the Leopold Park.

The contract which the Corporation submits for your approbation fixes the conditions on which this concession is made.

This arrangement appears so favorable to the interests of the City and to the needs of our higher education that we do not believe we need defend it at much length; we desire merely to reply to a few objections which might be raised.

1st—The Leopold Park is used at present for public festivals. Will it still be available for this purpose?

Plainly, yes. The piece of ground assigned to the two institutes is that on which stands the old château Dubois-Bianco; the belt surrounding it is taken up, beside, by the old aquarium and some grass plots, so that the public will still have the same amount of space as formerly.

Moreover, the employees of the City now housed in the old building, will be provided with new accomodations at the cost of Mons. Solvay.

2nd—Will not these Institutes be too far removed from the University?

They will be scarcely farther off than the hospitals to which the students go, or than the Institute of Botany generously founded by Mons. Leo Errera. In all University towns these Institutes are at considerable distances from each other. At Bonn they are far from the University, and outside the town, at Poppelsdorf; at Genoa the city has devoted a large park to their erection; at Paris the laboratories and institutes are

much scattered, some of them in the Bois de Boulogne and in the Park of Montsouris; at Ghent and at Liége the institutes, and especially that established by the generosity of Mons. Montefiore, are not attached to the buildings of the University.

Besides, the site which the Corporation proposes to you has the advantage of being in the near neighbourhood of the Museum of natural history, to which the students will need to have recourse.

Finally, we are in hopes that the first step generously taken by Mons. Solvay will be followed by others, that the example, too rare in our country, of an intelligent munificence such as that to which Switzerland, Greece, the United States and England owe admirable scientific institutions, will stimulate the emulation of those of our fellow-citizens who have been favoured by fortune, and will enable us hereafter to group other like establishments about the Solvay Institute; thus there may grow up, in the Leopold Park, a scientific city worthy of admiration, which, with the Museum to which the researches of its learned superintendent, Mons. Dupont, on our prehistoric fauna have given a universal reputation, may form, in the midst of the beautiful foliage of the park, a collection unlike any other in Europe.

Our university youth are not less eager for work than those of foreign universities, and we see them voluntarily going beyond the requirements of the official programmes, following free courses of lectures, applying themselves to the practical exercises set on foot by the University professors, publishing reviews, organizing meetings for conference; it is a part of our duty to furnish food in response to this thirst for knowledge, this desire for progress, and we cannot do so more beneficially or more efficaciously than by encouraging the foundation of special scientific institutes.

On these grounds, the Corporation proposes to you to adopt the following Agreement, which we have entered into with Mons. Solvay, subject to ratification by the Council.

The Corporation is fully persuaded that the Council, after ratifying this Agreement by a unanimous vote, will desire to testify its lively gratitude to the generous donor, Senator Solvay, by voting him its warmest thanks.

AGREEMENT WITH MONS. ERNEST SOLVAY.

Between the City of Brussels, represented by Mons. Buls, Burgomaster, acting with the approval of the Communal Council and the competent authorities, of the first part

And

Mons. Ernest Solvay, capitalist, having his residence at Ixelles, rue des Champs-Élysées, of the second part.

It has been set forth that Mons. Solvay, desiring on the one hand to extend the researches begun at the Solvay Institute in 1889 and eventually to carry out other scientific researches, and on the other hand to assist the City of Brussels to endow the University of this City with institutes and laboratories for practical study which are indispensable to it, has asked authority from the City of Brussels for the erection by him, in the Leopold Park, of buildings intended:

1st—For a scientific establishment, which is to bear the name of the Solvay Institute;
2nd—For a University Institute of Physiology, of which the University is to have the free disposal.

These proposals having been accepted, the following agreement is entered into between the parties.

Art. 1st—The City of Brussels accepts the offer of Mons. Solvay to erect a University Institute of Physiology, and places at his disposal, for this purpose, a piece of land, situated in the Leopold Park, containing about 360 square *mètres*, shown in blue on the accompanying map, and indicated by the letters A, B, C, D, E, F, G.

The City grants at the same time, for the erection of a scientific establishment which is to bear the name of the Solvay Institute, and this for a period of thirty years, beginning with the date at which this agreement shall become definitely effective, another piece of land, adjoining the former, shown in red on the accompanying map, indicated by the letters A, B, C, D, H, I, J, and containing about 950 square *mètres*.

These pieces of land are to be enclosed by walls following the line marked out by J, K, L and D, E, F.

A light enclosure, in conformity with suggestions to be given by the Corporation, will be established along the dotted red line shown on the map.

Art. 2nd—A belt, of about *72 ares*, round the plots of land marked on the map will continue to be used as at present, so long as this Agreement shall be in force, and no new building is to be erected upon it without the previous consent of both parties. This belt is indicated upon the accompanying map by a dotted line in black.

Art. 3rd—On the piece of ground set aside for the University Institute, Mons. Solvay pledges himself to put up buildings covering a minimum area of 220 square *mètres*, in accordance with what is marked out on the accompanying map.

On the piece of ground granted to Mons. Solvay for the Institute bearing his name, he pledges himself to put up a building covering a minimum area of 330 square *mètres*.

He reserves the right to erect afterwards on this land, if he so please, such other structures as he may consider useful for his scientific researches.

All the working drawings for the buildings in question are to be submitted to the Corporation for its approval.

Art. 4th—The buildings, of which the one is intended for the Solvay Institute and the other for the University Institute of Physiology, will include two distinct parts, but will form an architecturally connected whole.

Art. 5th—Mons. Solvay places at the disposal of the City of Brussels the sum of 10,000 francs, to be devoted to securing new quarters or building a dwelling for the keepers of the Leopold Park, an orangery, and a house for storing garden tools, in accordance with the plans of the Corporation.

Art. 6th—Mons. Solvay pledges himself to appropriate to the University Institute the sum of 200,000 francs, which is to serve both for the erection of the building and to contribute towards the furnishing and the completion of the scientific equipment at present employed for instruction in physiology.

He pledges himself to appropriate to the Solvay Institute a sum at least equal to that given to the University Institute.

The work of construction is to be carried on in such a way that both Institutes may be inaugurated within eighteen months from the delivery of the land, and the sum above mentioned for the University Institute will be expended by specific appropriations within three years from the said delivery.

Art. 7th—The buildings of the University Institute of Physiology and their fixed attachments will belong immediately to the City of Brussels, to which they will be delivered on the day of the inauguration.

The buildings forming the Solvay Institute, their furniture, and their scientific equipment, will belong, without recourse for damages, to the City of Brussels at the expiration, or on the cancellation of this present Agreement, no matter by what cause brought about.

Art. 8th—During the whole term of the grant Mons. Solvay makes himself responsible for all necessary repairs, reconstructions and renewals in connection with the Solvay Institute, so that the buildings and their furnishing shall be always kept in good condition.

Art. 9th—The corporation will adopt such measures as may

be necessary that Mons. Solvay and the personal staff managing and teaching in these Institutes shall always have access to their buildings and grounds by the *rue Belliard*.

The City binds itself, during the term of the contract, to maintain in its present condition the *allée* (tinted gray on the accompanying map) giving access to the *rue Belliard*.

Students or other persons resorting to these Institutes must conform to the regular hours for the opening and closing of the Park, as ordered or hereafter to be ordered by the Communal Administration, even to those temporarily put in force at the time of festivals, during the course of which access to the Institutes may be forbidden.

The premises of the Institutes are not to be under any circumstances, even partially or temporarily, diverted from their scientific purpose. No lease or transfer of them is to be permitted.

Art. 10th—Taxes, dues, and assessments of every kind levied or hereafter to be levied on the Solvay Institute, are in their entirety to be at the sole charge of Mons. Solvay during the whole term of the grant.

Art. 11th—It shall be lawful for the City of Brussels to hold the present Agreement as fully cancelled:

1st—In case the courses of instruction or the scientific researches which are the object of the institution shall be no longer regularly kept up; or

2nd—In case the obligation as to maintenance, stipulated in Art. 8th, or that in regard to taxes, stipulated in Art. 10th, be not fully carried out.

Art. 12th—All fiscal and other charges arising in connection with the legal passage of this Agreement are to be borne by Mons. Solvay.

This Agreement made in duplicate, at Brussels, on the 18th of June, 1892.

E. SOLVAY. BULS.

The Communal Council, after hearing remarks from MM. Lemonnier, Kops and Bède, unanimously adopted the agreement which was submitted to it, and by vote determined at the same time to call in a body upon Mons. Solvay, in order to thank him in the name of the City of Brussels, and to present to him a commemorative medal.

The preparation of this medal was entrusted to the sculptor Fernand Dubois.

The presentation was made, on the 19th of May, 1892, by a deputation of the Communal Council, composed of MM. Buls, Burgomaster of Brussels, André, De Potter, De Mot and Janssen, Aldermen of the City, and Professor Depaire, senior member of the Council.

The Burgomaster addressed the donor in the following terms:

"The Corporation of Aldermen of Brussels, accompanied by the senior member of the Communal Council, calls upon you, in pursuance of an official vote, in order to present to you an expression of its lively admiration and its profound gratitude for the generous act by which you have endowed the City of Brussels with a University Institute. Science is but little accustomed among us to such acts of munificence. It has required the bold first step of a courageous worker and a man of science like yourself, disposing of a fortune acquired by persevering labour, in the light of a remarkable power of intuition which looks forward in advance for the solution of scientific problems, to give amongst us a powerful impulse to the pursuit of the most delicate investigations, of researches into the greatest mysteries of the principle of life.

"You have raised up around you an industrious swarm of scientific bees, seekers after truth, animated by your eagerness for discovery, filled with your thirst for knowledge, penetrated by your faith in the unlimited progress of science.

"Presenting to you these medals in the name of the Communal Council, we thank you then, not only for the gen-

erous gifts by which our educational system will be benefitted, but also for the example you have given, which has already stimulated others about you to noble emulation.

"Brussels, but yesterday so poor in scientific institutions, will to-morrow be able, thanks to you, to point with pride, in a park dedicated to science, to the busy hives in which the progress of future knowledge shall be worked out.

"The Communal Council has wished that there might remain a visible evidence of its gratitude, and thus that the date of the foundation of the Solvay Institute, and the features of its eminent founder, should be stamped upon the medals which we now present you in its name."

The casket presented by the Burgomaster contained three medals: one in gold, a second in silver, and the third in bronze.

On the obverse of each of these is represented the profile of the donor, encircled by this inscription: *La Ville de Bruxelles reconnaissante à Ernest Solvay.* On the reverse, an allegorical figure representing Science, with an inscription: *Omnia in mensurâ*, and beneath: *Fondation des Instituts universitaires, 4 Juillet, 1892.*

A copy of these medals will be deposited in the Communal Museum, and another copy placed beneath the corner stone of the new institution.